

## CLAIMS

What is claimed is:

1. A zero excess bandwidth modulation method, the method comprising:  
encoding a plurality of information bits, thereby generating a sequence of  
5 discrete-valued modulation symbols;

TH (Tomlinson-Harashima) precoding of the sequence of discrete-valued modulation symbols according to a predetermined overall channel symbol response having spectral zeroes at edges of a corresponding Nyquist band, thereby generating a plurality of discrete-time transmit signals at a modulation rate;

10 inserting the plurality of discrete-time transmit signals into means to generate a continuous-time transmit signal by appropriate discrete-time filtering, digital-to-analog conversion (DAC), and continuous-time filtering;

15 ensuring, within the means to generate the continuous-time transmit signal, that the continuous-time transmit signal has spectral zeroes at the edges of the corresponding Nyquist band, which equals a bandwidth of the available transmission band, and that any spectral components outside of the available transmission band are substantially suppressed; and

20 launching the filtered, continuous-time transmit signal into the communication channel.

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2. The method of claim 1, wherein:

the predetermined overall channel response is characterized as

$$h(D) = 1 + h_1 D + h_2 D^2 + \dots;$$

$$D = e^{-j2\pi fT} (= z^{-1});$$

25  $f$  is frequency;

$T$  is an inverse of the bandwidth of the available transmission band;

$h_1, h_2, \dots$  are constant valued coefficients; and

$h(D)$  is zero when  $D = -1$ .

30 3. The method of claim 1, wherein the encoding of the plurality of information bits further comprises:

encoding of the plurality of information bits into a plurality of encoded bits; and

5 mapping the plurality of encoded bits into a plurality of modulation symbols according to a symbol constellation and a corresponding mapping function, thereby generating the sequence of discrete-valued modulation symbols.

4. The method of claim 1, wherein the encoding of the plurality of information bits further comprises:

10 encoding a subset of information bits of the plurality of information bits into a plurality of encoded bits; and

mapping the plurality of encoded bits and at least one uncoded information bits into a plurality of modulation symbols according to a symbol constellation and a corresponding mapping function, thereby generating the sequence of discrete-valued modulation symbols.

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5. The method of claim 1, wherein:

TH precoding operates on the discrete-valued modulation symbols to perform an inverse filtering operation in accordance with the predetermined overall channel symbol response and executes modulo operations to limit signals within a 20 predetermined signal region, thereby generating the plurality of discrete-time transmit signals at the modulation rate.

6. The method of claim 1, wherein:

25 the sequence of discrete-valued modulation symbols has a modulation type of at least one of PAM (pulse amplitude modulation), QPSK (quadrature phase shift keying), 16 QAM (quadrature amplitude modulation), and a higher-order QAM.

7. The method of claim 1, wherein:

30 the encoding of the plurality of information bits thereby generating the sequence of discrete-valued modulation symbols involves at least one of uncoded modulation, TCM (trellis coded modulation), TTSM (turbo trellis coded modulation),

LDPC (low density parity check) encoding and modulation, and concatenated encoding and modulation.

8. The method of claim 1, wherein:

5 the method is performed cooperatively within a communication transmitter and a communication receiver that are communicatively coupled via the communication channel.

9. The method of claim 1, further comprising:

10 receiving a continuous-time receive signal from the communication channel; converting the continuous-time receive signal into a discrete-time signal by means to perform appropriate continuous-time filtering, ADC (analog-to-digital conversion), and discrete-time filtering, thereby obtaining a plurality of discrete-time receive signals at the modulation rate;

15 ensuring, within the means to perform appropriate continuous-time filtering, ADC, and discrete-time filtering, that any signal and noise components outside of the available transmission band is suppressed and that the discrete-time receive signal is shaped into a form corresponding to the predetermined overall channel symbol response that is assumed for the TH precoding, and

20 decoding the plurality of discrete-time receive signals to generate best estimates of the sequence of discrete-valued modulation symbols and the information bits encoded therein.

10. The method of claim 9, further comprising:

25 performing adaptive equalization when ensuring that the discrete-time receive signal is shaped into a form corresponding to the predetermined overall channel symbol response that is assumed for the TH precoding.

11. The method of claim 1, wherein:

30 the predetermined overall channel symbol response employed for TH precoding, referred to as  $h(D)$ , is a finite impulse response (FIR)

$h(D) = 1 + h_1 D + h_2 D^2 + \dots + h_L D^L$  for some finite positive integer  $L$ , or an infinite impulse response (IIR)  $h(D) = p(D)/q(D)$ ;

$p(D) = 1 + p_1 D + \dots + p_P D^P$  and  $q(D) = 1 + q_1 D + \dots + q_Q D^Q$  for some finite positive integers  $P$  and  $Q$ ; and

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12. The method of claim 11, wherein:

$h(D) = (1 + D)/(1 - \rho D)$  for  $0 < \rho < 1$ .

13. A zero excess bandwidth modulation communication transmitter, the transmitter comprising:

an encoder and symbol mapper that encodes a plurality of information bits, thereby generating a sequence of discrete-valued modulation symbols;

5 a TH (Tomlinson-Harashima) precoder that performs precoding of the sequence of discrete-valued modulation symbols according to a predetermined overall channel symbol response having spectral zeroes at edges of a corresponding Nyquist band, thereby generating a plurality of discrete-time transmit signals at a modulation rate;

means to generate a continuous-time transmit signal by appropriate discrete-10 time filtering, digital-to-analog conversion (DAC), and continuous-time filtering;

wherein the plurality of discrete-time transmit signals is inserted into the means;

wherein the means ensures that the continuous-time transmit signal has spectral zeroes at the edges of the corresponding Nyquist band, which equals a bandwidth of 15 the available transmission band, and that any spectral components outside of the available transmission band are substantially suppressed; and

wherein the filtered, continuous-time transmit signal is launched into the communication channel from the transmit filter.

20 14. The transmitter of claim 13, wherein:

the predetermined overall channel response is characterized as  
$$h(D) = 1 + h_1 D + h_2 D^2 + \dots;$$

$D = e^{-j2\pi fT} (= z^{-1})$ ;

f is frequency;

25 T is an inverse of the bandwidth of the available transmission band;

$h_1, h_2, \dots$  are constant valued coefficients; and

$h(D)$  is zero when  $D = -1$ .

15. The transmitter of claim 13, wherein:

30 the encoder and symbol mapper encodes the plurality of information bits into a plurality of encoded bits; and

the encoder and symbol mapper maps the plurality of encoded bits into a plurality of modulation symbols according to a symbol constellation and a corresponding mapping function, thereby generating the sequence of discrete-valued modulation symbols.

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16. The transmitter of claim 13, wherein:

the encoder and symbol mapper encodes a subset of information bits of the plurality of information bits into a plurality of encoded bits; and

10 the encoder and symbol mapper maps the plurality of encoded bits and at least one uncoded information bits into a plurality of modulation symbols according to a symbol constellation and a corresponding mapping function, thereby generating the sequence of discrete-valued modulation symbols.

17. The transmitter of claim 13, wherein:

15 the TH precoder operates on the discrete-valued modulation symbols to perform an inverse filtering operation in accordance with the predetermined overall channel symbol response and executes modulo operations to limit signals within a predetermined signal region, thereby generating the plurality of discrete-time transmit signals at the modulation rate.

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18. The transmitter of claim 13, wherein:

the sequence of discrete-valued modulation symbols has a modulation type of at least one of PAM (pulse amplitude modulation), QPSK (quadrature phase shift keying), 16 QAM (quadrature amplitude modulation), and a higher-order QAM.

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19. The transmitter of claim 13, wherein:

the encoder and symbol mapper performs encoding of the plurality of information bits, thereby generating the sequence of discrete-valued modulation symbols, that involves at least one of uncoded modulation, TCM (trellis coded modulation), TTCM (turbo trellis coded modulation), LDPC (low density parity check) encoding and modulation, and concatenated encoding and modulation.

20. The transmitter of claim 13, wherein:

the communication transmitter is communicatively coupled to a communication receiver via the communication channel; and

5 the communication transmitter, the communication receiver, and the communication channel form a communication system.

21. The communication system of claim 20, wherein:

the communication receiver receives a continuous-time receive signal from the 10 communication channel;

the communication receiver converts the continuous-time receive signal into a discrete-time signal using means to perform appropriate continuous-time filtering, ADC (analog-to-digital conversion), and discrete-time filtering, thereby obtaining a plurality of discrete-time receive signals at the modulation rate;

15 the communication receiver ensures, within the means to perform appropriate continuous-time filtering, ADC, and discrete-time filtering, that any signal and noise components outside of the available transmission band is suppressed and that the discrete-time receive signal is shaped into a form corresponding to the predetermined overall channel symbol response that is assumed for the TH precoding, and

20 the communication receiver performs decoding of the plurality of discrete-time receive signals to generate best estimates of the sequence of discrete-valued modulation symbols and the information bits encoded therein.

22. The communication system of claim 21, wherein:

25 the communication receiver performs adaptive equalization when ensuring that the discrete-time receive signal is shaped into a form corresponding to the predetermined overall channel symbol response that is assumed for the TH precoding.

23. The transmitter of claim 13, wherein:

30 the predetermined overall channel symbol response employed by the TH precoder, referred to as  $h(D)$ , is a finite impulse response (FIR)

$h(D) = 1 + h_1 D + h_2 D^2 + \dots + h_L D^L$  for some finite positive integer  $L$ , or an infinite impulse response (IIR)  $h(D) = p(D)/q(D)$ ;

$p(D) = 1 + p_1 D + \dots + p_P D^P$  and  $q(D) = 1 + q_1 D + \dots + q_Q D^Q$  for some finite positive integers  $P$  and  $Q$ ; and

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24. The transmitter of claim 23, wherein:

for  $0 < \rho < 1$ .